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QUENCHD: AN ANALYSIS CODE FOR QUENCH EVENTS IN TEVATRON MAGNETS*

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I. INTRODUCTION

The Tevatron has successfully finished the commissioning period at Fermi National Accelerator Laboratory and has become the first operating high-energy accelerator to use superconducting magnets. Operational plans are to improve reliability and to understand the systematics of accelerator operations. Experience gained during this period will point to new directions in the use of superconducting technology in accelerator science and the colliding-beam physics of 1-TeV protons on 1-TeV antiprotons.

There are ten major sources of accelerator downtime which affect both reliability and maintenance.[1] The greatest source of downtime is magnet quenches, which are a process which changes the electrical conductivity of metals in the magnet coil by heating them to temperatures at which superconductivity cannot be sustained. Quenches are detected by a microprocessor-driven system which sequentially measures voltage drops across each half-cell of magnets[2] and monitors these measurements to a sensitivity of 0.02 V, the resistive voltage drop which indicates the start of a quench. Each microprocessor monitors eight to ten half-cells, analog signals, and the status of external interlocks. The primary output from the microprocessor is an enabling signal which permits magnet power-supply operation and inhibits the energy-dump system until a quench or other unusual condition[3] occurs. If an unusual condition does occur, the power supply is shut off, the current is diverted around the quenched unit, and the stored energy in the quenched cell is dumped.

The objective of this report is to introduce the code QUENCHD, a package to study the statistical correlations which exist between quench parameters, and to create a data base which organizes this information into an acceptable format for project analysis. The code can be used to find relationships between quenches and magnet current, beam energy, magnet position in a particular cell, elapsed time between successive quenches, and operation of the accelerator in either the fixed-target or the colliding-beam mode.

II. QUENCH DATA

A collection of quench data can be found in the Operational Statistical Reports 1984-1985, private notes compiled by workers in the cryogenics group, and the Circular Buffer and Downtime Log computer files on the Operational VAX. This collection constitutes a data base, the QUENCHD files, and is stored on the CDC CYBER system as three permanent files: ITAPE, the input data file, TAPE7, the output data file which is copied into ITAPE after the job ends and TAPE8, the output scratch file or extra copy of the data base. Since permanent files are archived three times daily on the CYBER, the user has the opportunity to retrieve information lost during editing sessions or overwritten when several program versions have been executed.

There are two procedure files which control all operations of the interactive job: QUCCL, the file which attaches the compiled version of QUENCHD, system libraries, and system utilities; and QUCOPY, the file which copies the current version of TAPE7 onto TAPE8 and has the option of printing hard copies of the data base. Figure 1 shows a flowchart of the QUENCHD files.

III. THE PROGRAM QUENCHD

There are five program options in QUENCHD: 1) Data Entry and Storage, 2) Printing Data, 3) Changing Data, 4) Plotting and Analysis of Data, and 5) Closing the Output Files. Calls to options (1) through (4) are repeatable during the job, and the prompts are presented with accompanying tutorial guides.

Data Entry and Storage

The complete description of a quench event requires seven parameters formatted to fit on one line. The quench parameters and their data formats are explained in Table I.

Table I. Quench Parameters and Data

Parameter	Parameter Description	Fortran Data Format
CELL(ID)	magnet cell name with (M) identifying a multihouse quench, A11M	A4
ENERGY	beam energy at quench or energy established by magnet ramp (GeV), 0800	I4
CURRENT	magnet current at quench in (A), 3992	I4
TIME	time of quench (hhmm), 2300	I4
DATE	calendar date of quench (YYMMDD), 850921	I6
CODE	serial code to identify quench, cell, and number; (1110005) represents the fifth quench in cell A11	I7
COMMENT	a 10 character comment (150GEVRMP_) 150 GeV ramp	A10

Quench parameters are stored in the data base as chronologically ordered events within each cell. The program calculates a unique seven- digit code[4] for each event and sorts these codes with a modified version of the QUICKSORT algorithm developed at SLAC.[5] One advantage QUICKSORT has over conventional sorting routines is the use of pivotal points, or multiple centers where separate binary sorts are performed. Thus a simple binary method requires $o(2^N)$ seconds to sort N quenches, while QUICKSORT requires only $o(N*\ell nN)$ seconds to sort the same N quenches.

Printing Data

The printing module in QUENCHD accesses events in the data base and prints them on the terminal. Initially, the user selects one of the following four options: 1) Print Quench Data in N Cells, 2) Select an Event Subsample to Print, 3) Write Data into Output Files, and 4) Stop Print Options. The program remains in the printing loop until print option (4) is selected. It is important for the user to select print option (2) before entering new information into the data base. Such a check can prevent the nuisance of duplicating results.

Changing Data

The editor mode in QUENCHD changes elements in the data base. If several identical changes are requested, the editor automatically enters the new values into TAPE7 and TAPE8, and echoes back both versions to the terminal. New entries become a permanent part of the data base after TAPE7 is closed. Thus, this editing cycle continues whenever new changes occur.

Plotting Data and Analysis

The plotting module generates histograms from a collection of HBOOK, CERNLIB, and GRALIB program libraries,[6] and a plotting subroutine in QUENCHD. The plotting package generates four histograms: 1) The Quench Distribution as a Function of Cell Number 2) The Distribution of Beam Energy at Quench, 3) The Distribution of Magnet Current at Quench, and 4) The Application of One or Two Parameter Cuts to Histogram (1), (2), or (3). There are six parameter cuts in the module and each is assigned a minimum and a maximum value to select a particular event subsample for study. These parameters are the cell number, the beam energy, the magnet current, the time of quench, the date of quench, and the event identification code. See Figures 2 through 5 for an application of these plots to 256 quench events.

Closing the Output Files

Program option (5) closes the output files TAPE7 and TAPE8. When execution stops HBOOK surveys the contents of its data banks and displays the number of histograms to be plotted. If the number is greater than zero the user is prompted to scale plots, to prevue each one, and to route the results to the Benson Varian Plotter. If the number of plots is zero, the job simply stops.

IV. EXAMPLE OF A QUENCHD APPLICATION

The appendix illustrates the actual working instructions used to run QUENCHD. The example covers data entry, two of the four printing options, and the editing option. The plotting and graphical analysis options must be conducted on a "Tektronics 4010 Terminal" or on a similar device. The instructions are included with each prompt echoed onto the terminal.

ACKNOWLEDGEMENTS

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REFERENCES

1. C. Rode, **Fermilab Report**, July/August 1985, p.14–22.

2. The half-cell of magnets, i.e., the quench protection unit, has four dipoles and one quadrupole.

3. Quenches, overvoltage, lead runaway, overcurrent, etc. See R. Flora and G. Tool, Fermilab TM-867, March 1979.

4. See the parameter CODE in Table I.

5. R. C. Singleton, Algorithm 347, CACM, **12(3)**, 1969, 185–7.

6. HBOOK and CERNLIB are Fortran-77 program libraries from CERN; GRALIB is a graphics library for Fortran-77 applications written by the Fermilab Computer Department.

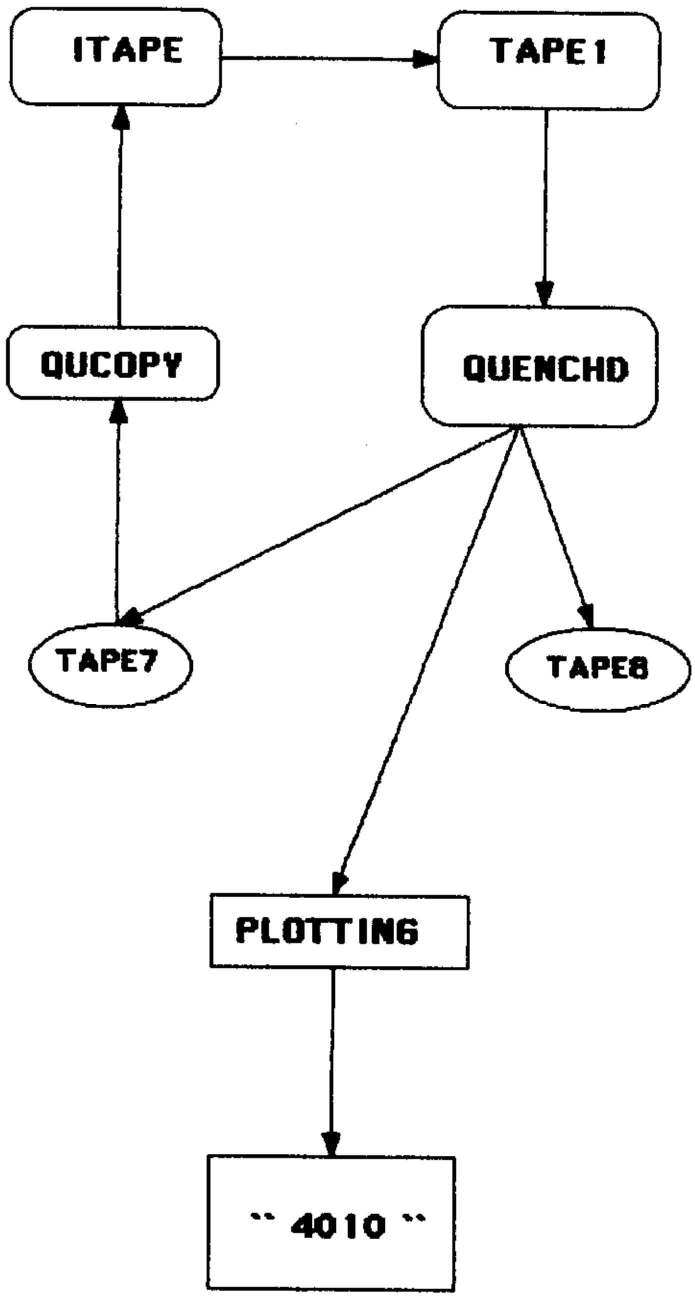

Figure 1. QUENCHD Files

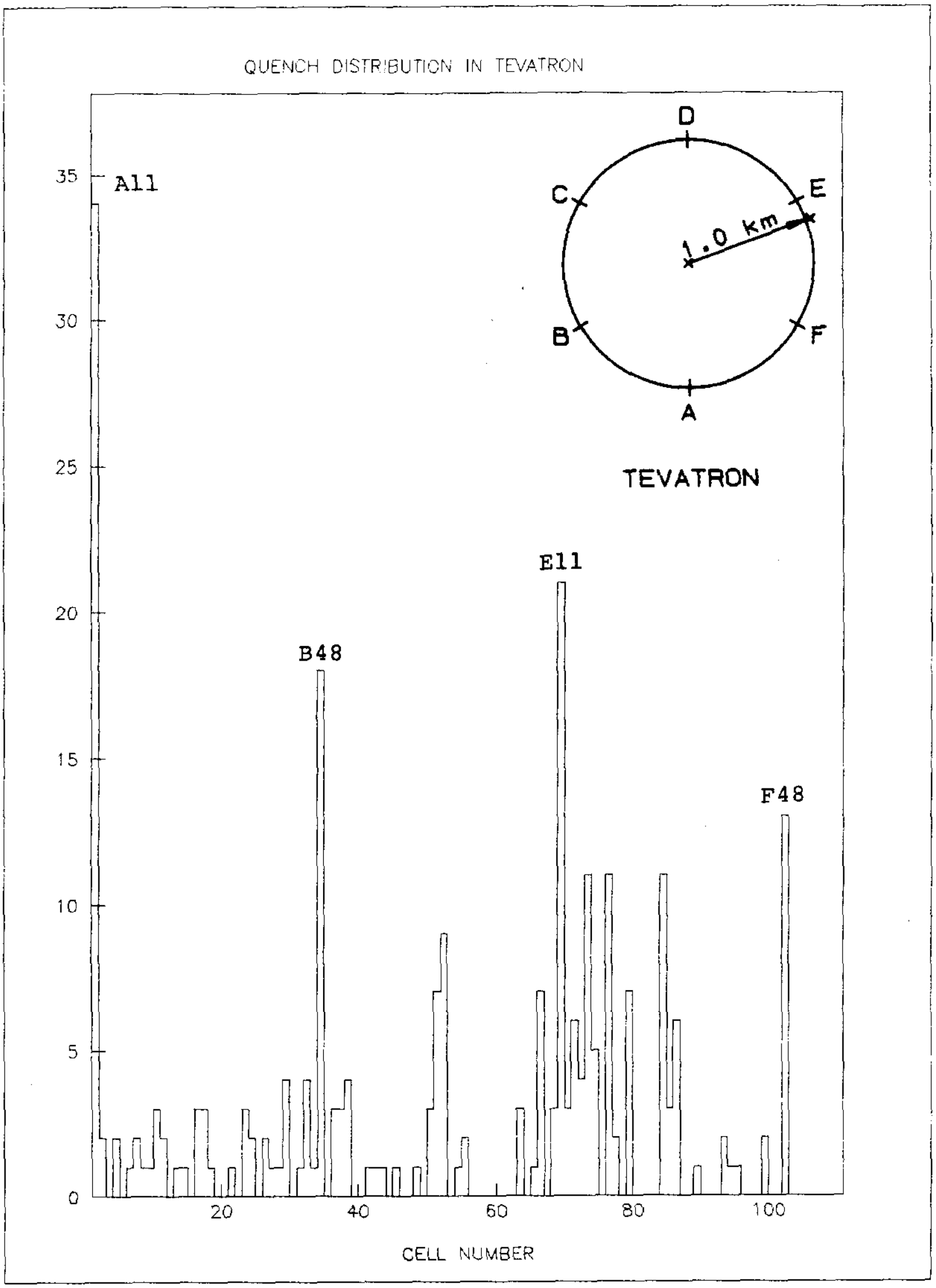

Figure 2. Distribution of Quenches in Tevatron
NEVENTS = 257

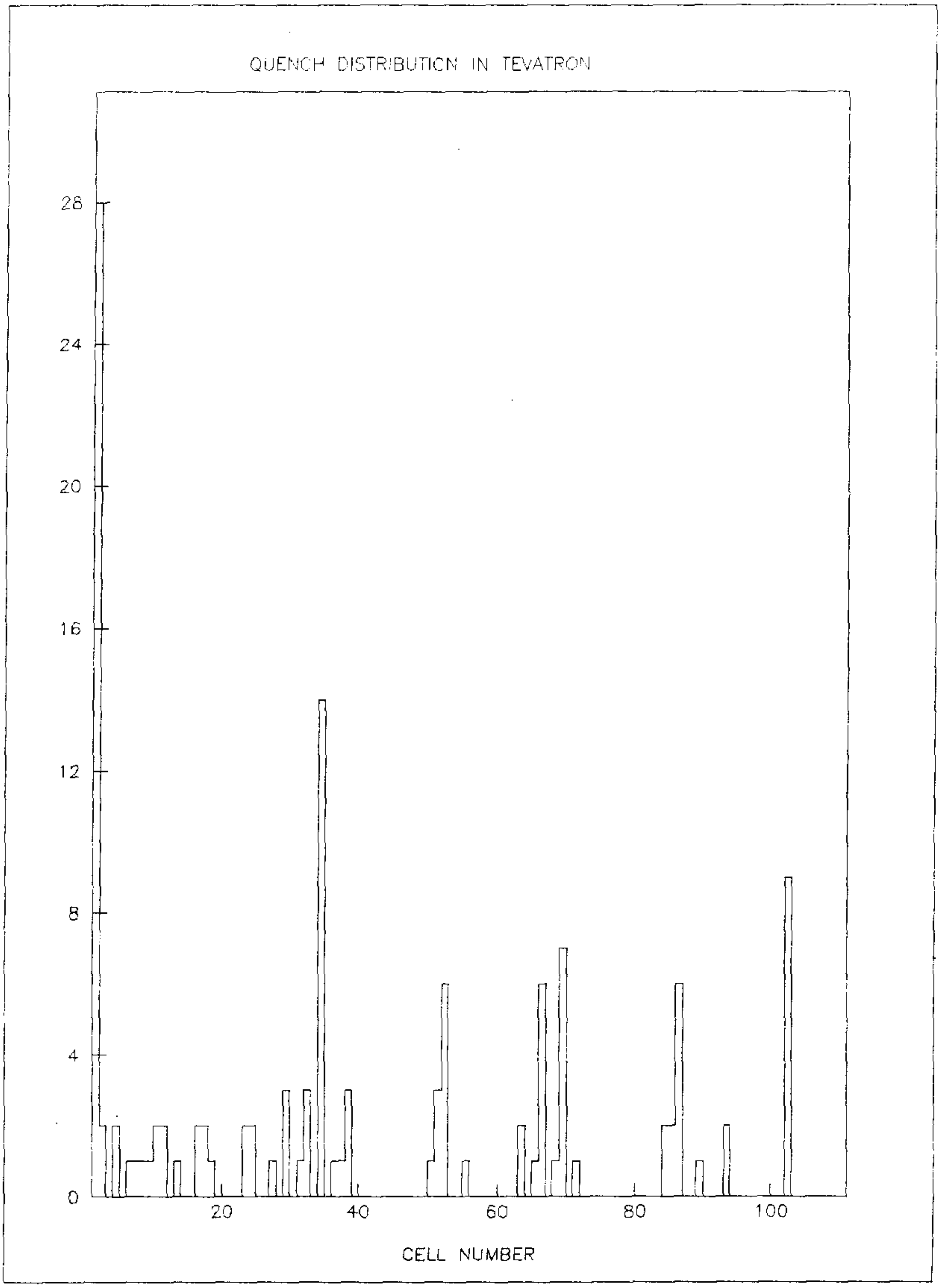

Figure 3. Distribution of Quenches in Tevatron
3000 A < Magnet Current < 5000 A
NEVENTS = 128

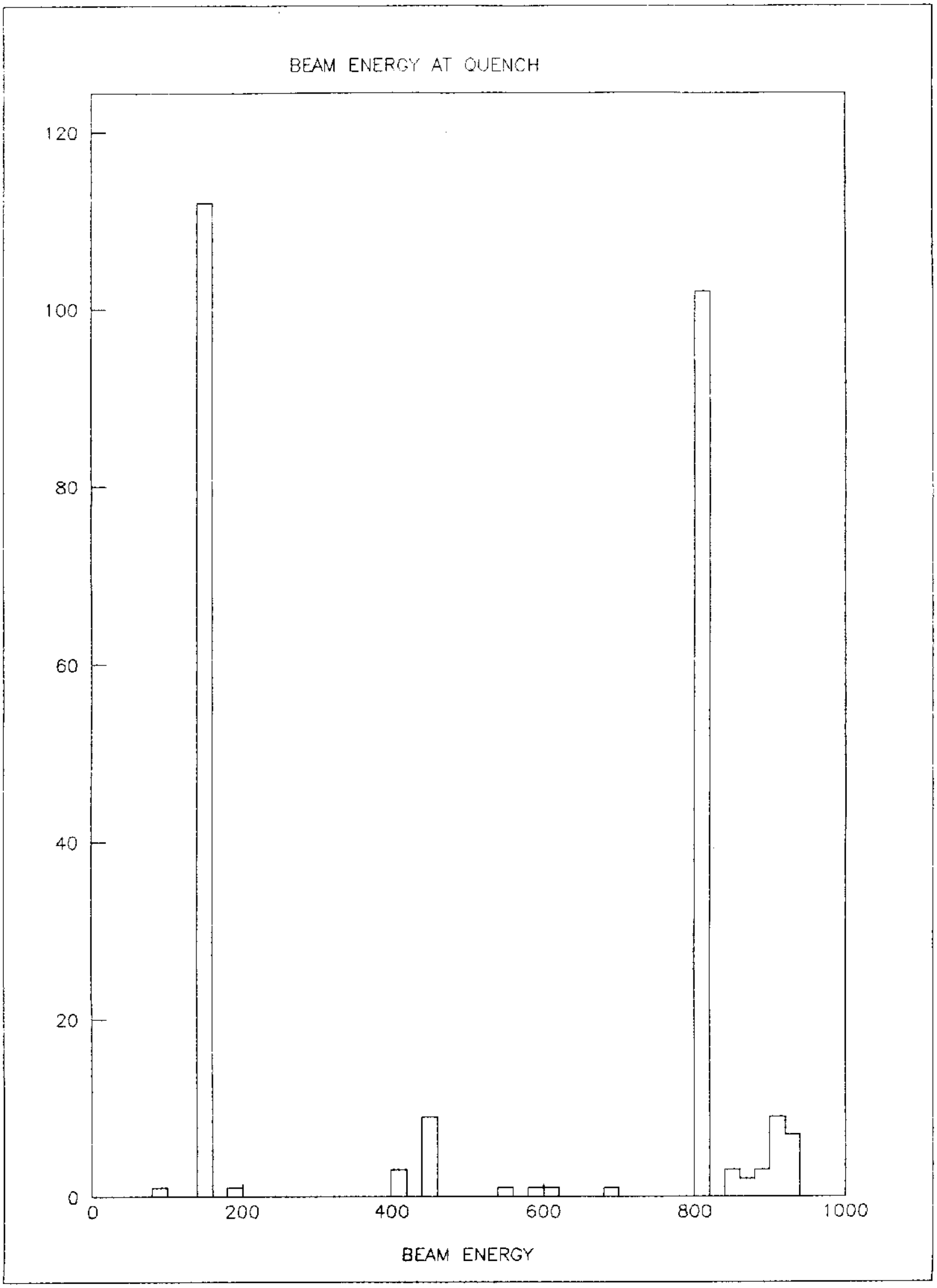

Figure 4. Distribution of Beam Energy at Quench
NEVENTS = 257

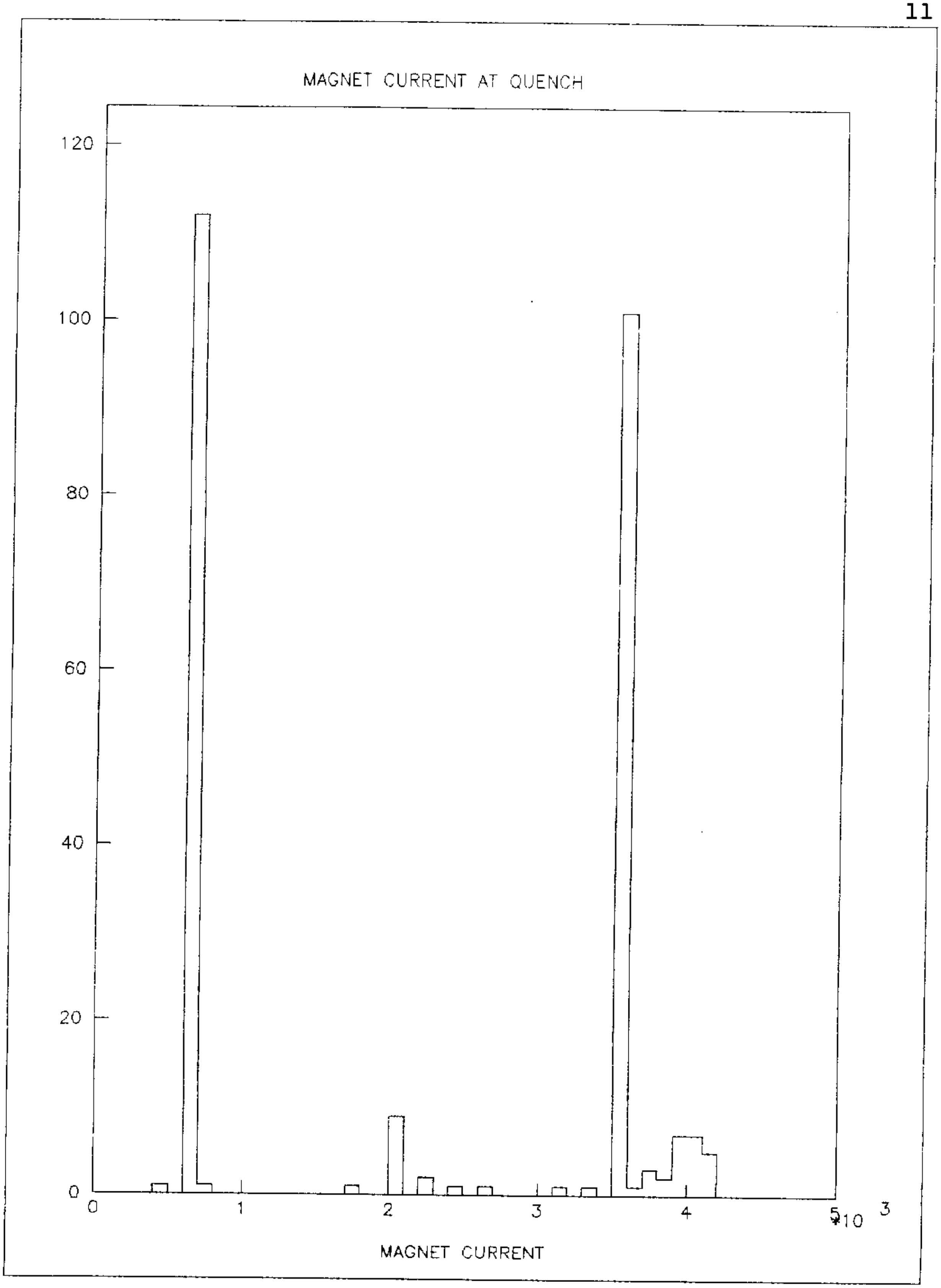

Figure 5. Distribution of Magnet Current at Quench
NEVENTS = 257

APPENDIX

```
WELCOME TO THE NOS SOFTWARE SYSTEM.
COPYRIGHT CONTROL DATA 1978, 1983.

86/02/03. 12.15.58. TA45
FERMILAB 4 X CYBER (875/GG).          NOS 2.2 596/587.
USER NAME: G2,[redacted]
JSN: ACDE, NAMIAF


/-,QUCCL,0,0


QUENCHL HAS 5 OPTIONS....................
(1) STORES AND SORTS QUENCH DATA IN LARGE ARRAYS.
(2) PRINTS PARTIAL OR TOTAL LISTS OF DATA.
(3) PLOTS QUENCH PARAMETERS FOR ANALYSIS.
(4) CHANGES DATA.
(5) STOPS EXECUTION WITHOUT LOSS OF DATA.

  *CHOOSE OPTION...
? 1

  *ENTER THE NUMBER OF QUENCHES ....
? 1

  *ENTER CELLID? ENER? CURR? TIME? DATE? CODE? COMM?
? C46_,0000,2500,0000,850101,346,BEAM LOSS


QUENCHL HAS 5 OPTIONS....................
(1) STORES AND SORTS QUENCH DATA IN LARGE ARRAYS.
(2) PRINTS PARTIAL OR TOTAL LISTS OF DATA.
(3) PLOTS QUENCH PARAMETERS FOR ANALYSIS.
(4) CHANGES DATA.
(5) STOPS EXECUTION WITHOUT LOSS OF DATA.

  *CHOOSE OPTION...
? 2

  *PRINT OPTIONS ARE....
(1) PRINT QUENCH DATA IN N? CELLS...
(2) SELECT SUBSAMPLE TO PRINT...
(3) WRITE OUTPUT FILE...
(4) DO NOT PRINT...RETURN...

  *CHOOSE PRINT OPTION...
?
```

```
  2

  *SELECT THE DATA CUT, 2=EN,3=CUR,4=TM,5=DT,6=CD
? 6

  *SELECT CUT1 AND CUT2 FOR SUBJECT(N)...
? 3460000,3469999
C46_   563.   2500.      0.   850101.   3460001.  BEAM LOSS
C46M   800.   3552.   1117.   850105.   3460002.  F2 TRAN SH
C46_   180.    799.   1850.   850425.   3460003.  ???
C46M   150.    666.    711.   850810.   3460004.  HFU#31DISC

 NUMBER OF EVENTS =     4

  *PRINT OPTIONS ARE....
(1) PRINT QUENCH DATA IN N? CELLS...
(2) SELECT SUBSAMPLE TO PRINT...
(3) WRITE OUTPUT FILE...
(4) DO NOT PRINT...RETURN...

  *CHOOSE PRINT OPTION...
? 1
          *** TOTAL NUMBER OF QUENCHES == 257

  *ENTER NUMBER OF CELLS TO PRINT...
? 1
A11M   800.   3550.   1117.   850105.   1110001.  F2 TRAN SH

  *PRINT OPTIONS ARE....
(1) PRINT QUENCH DATA IN N? CELLS...
(2) SELECT SUBSAMPLE TO PRINT...
(3) WRITE OUTPUT FILE...
(4) DO NOT PRINT...RETURN...

  *CHOOSE PRINT OPTION...
? 4


QUENCHL HAS 5 OPTIONS....................
(1) STORES AND SORTS QUENCH DATA IN LARGE ARRAYS.
(2) PRINTS PARTIAL OR TOTAL LISTS OF DATA.
(3) PLOTS QUENCH PARAMETERS FOR ANALYSIS.
(4) CHANGES DATA.
(5) STOPS EXECUTION WITHOUT LOSS OF DATA.

  *CHOOSE OPTION...
? 4

  *TO CHANGE DATA ENTER....
(1) ATTRIBUTE (1=CL,2=EN,3=CU,4=TM,5=DT,6=CD,7=CM)...
(2) THE QUENCH CODE.....
(3) NEW VALUE.....
?
```

```
  7
? 3460001
? BEAM LOSSQ

 SINGLE OR REPEATED ENTRIES ? (S) OR (R)...
? S

 OLD VALUE = BEAM LOSS

 NEW VALUE = BEAM LOSSQ

 MAKE MORE CHANGES ?...(Y) OR (N)....
? N


QUENCHL HAS 5 OPTIONS....................
(1) STORES AND SORTS QUENCH DATA IN LARGE ARRAYS.
(2) PRINTS PARTIAL OR TOTAL LISTS OF DATA.
(3) PLOTS QUENCH PARAMETERS FOR ANALYSIS.
(4) CHANGES DATA.
(5) STOPS EXECUTION WITHOUT LOSS OF DATA.

  *CHOOSE OPTION...
?  5


 ..............................................................................
 .
 .                                  H P L O T 4.10  TERMINATING.
 .
 .                                    0 PLOTS HAVE BEEN PRODUCED
 .
 ..............................................................................


$REVERT.CCL
/-,QUCOPY,0
 EXIT.
/


 BYE
UN=G2       LOG OFF  12.22.00.
JSN=ACDE     SRU-S        3.754
IAF     CONNECT TIME 00.05.46.
LOGGED OUT.

HOST DISCONNECTED   CONTROL CHARACTER=(ESC)
ENTER INPUT TO CONNECT TO HOST

FERMILAB =
```